Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

ORIGINATION OF SELF-GENERATING MATTER AND THE INFLUENCE OF ARIDITY UPON ITS EVOLUTIONARY DEVELOPMENT

DR. D. T. MACDOUGAL

XV

Any attempt at an interpretation of a desert landscape, with its diversity of forms, isolation of individuals, and scarcity of organic matter in the soil, leads inevitably to a consideration of the theoretical conditions which would be necessary in the origination of the physical basis of life, its development into organisms known to us in the living and fossil state, and also of the possibilities of the occurrence of a re-generation at the present time.

From almost every excursion which the biologist has made into this inviting field of speculation on which he has called to his aid various extreme or unusual intensities of the factors to be taken into account, he has been ruthlessly recalled by the geological historian with the reminder that the general composition of the atmosphere, its pressure, the temperatures, and other conditions prevalent on the earth's surface were uniform and continuous with those now encountered and not widely different, in their total departure, in any stage of terrestrial development in which life might have originated.

Now we are not able to discover that living or self-generating matter is actually being formed anew on the earth's surface at the present time, and in the absence of positive evidence we are compelled to say that all life now in existence must have descended from forms which had their ultimate origin in other times and under other conditions than those now prevalent.

A consideration of the phyletic aspects of fossil and living forms of plants yields but little, which might serve as an indication of the conditions under which the earlier forms developed. Even the earliest remains include such advanced types as the ferns and cycads. The amount of progress represented by the derivation of the gametopetalous seed-plants from these, in comparison with the preceding evolution, is quite insignificant, while even the simpler forms of animals and plants are to be considered as types widely divergent from primitive self-generating matter, being removed from it by the slow but sure advances of untold millions of years of development.

It is, therefore, as if we had observed the events and objects of yesterday and were called upon to read the history of the past century. In the search for supporting ideas upon which to base speculation, two conceptions serve as encouragement for a renewed attack upon this fascinating problem. One is embraced by Chamberlin's planetesimal theory of the growth of the earth and the attendant modification of surface conditions, which necessarily showed a complex widely different from the present, and the other is one, growing in favor with physiologists, to the effect that the essential activities of living matter rest upon catalysis, and enzymatic processes, with the characteristic reaction velocities directly affected by internal and external limiting factors. The protamic nucleus may be taken to represent the first form in which self-generating matter might be said to have the characters of protoplasm, but previously to its synthesis there must have occurred an increasingly complex series of carbon compounds, with hydrogen, oxygen, nitrogen, sulphur, and phosphorus, while iron, calcium, magnesium, and potassium are also involved in its activities at the present time. That these main constituents were present in the atmosphere at partial pressures of varying intensity, and that unstable carbides, nitrates, phosphides, and sulphides brought by infalling planetesimals were passing into more stable unions with the formation of hydrocarbons, ammonia, hydrogen phosphide, etc., is suggested by Chamberlin, and the possible interactions and combinations might result in the synthesis of very complex substances, well up toward the simpler forms of living matter. The hypothesis formulated by him also assumes that the surface of the earth was unworn piled talus, but little of which had gone into solution. The development of the hydrosphere moistening this layer, and forming pools and small bodies of water all exposed to the light of the sun, together with the variations in temperature, partly due to the heat of impact of infalling bodies, the influence of magnetic fields induced by bodies circulating about the earth would determine the paths of ions and electrons traversing them, while in addition other states of ionization, due to radioactivity, would all be possible factors contributory to a synthesis that might form a beginning of the physical basis of life. Any resulting thermocatalyzer would be a possible agent for self-organization, and in the development of an organic type its characteristic activities would consist in the degradation, or reduction of the potential energy of the medium or substratum and the oxidation of the acquired substances. Living matter is in fact a thermal engine in which the oxidation is, comparatively, exceedingly slow.

FIG. 1.—Mud-volcanoes of Lower California, in and around which unusual opportunities for chemical combination are offered by the conditions of temperature and pressure.

No process observable by available physiological methods suggests the origination of living matter, yet it seems quite probable that combinations similar, analogous, or even identical with the earliest forms of living matter might be produced in the laboratory, in inclosed spaces or under special conditions. Doubtless compounds of much greater intricacy have been made, but while we might make such substances, yet it would be extremely difficult for us to furnish the supply of material and the continuance of conditions which would permit this matter to exercise its initial functions of self-generation to any appreciable extent. The starting of a strain of living matter which might perpetuate itself and evolve into differentiated forms will long remain one of the most difficult feats which confronts the experimenter. The tests and criticisms which have been applied to the results of the few essays that have been made for the production of bodies which would be self-maintenant in a suitable medium, have been, for the most part, misdirected. Thus in the consideration of the hitherto unsuccessful efforts to produce bodies simulating some of the properties of self-generating matter, tests for the physical and chemical properties of protoplasm as well as for phenomena of the cell have been applied, regardless of the fact that the cell probably stands removed by a million years of evolution from the simple living material which first took shape, and represents, in fact, simply a successful form of organism and by no means the only possible morphological organization.

Such misuse of criteria has doubtless operated to curb research and discourage experimentation, and while it may have seemed soundly conservative for Kelvin to say:

> But let not youthful minds be dazzled by the imaginings of the daily newspapers that because Berthelot and others have thus made foodstuffs they can make living things, or that there is any prospect of a process being found in any laboratory for making a living thing. . . . . There is an absolute distinction between crystals and cells. Nothing approaching to the cell of a living creature has ever yet been made,[1]

yet the actual accomplishment of self-generating matter is, as suggested above, a theoretical possibility in the laboratory. The provision of a proper nutritive environment would present greater difficulties than the construction of a thermo-catalyzer capable of sustaining itself in a proper medium.

After growth and decay, the next most important property of living matter is that of irritability, of impressibility, and of accommodation to environment. The basic substance of protoplasm endured because of a capacity for withstanding the current range of temperature and insolation, and this endurance was made possible by fairly automatic adjustments, one of the simplest of which is encountered in recognizable form in living plants today in the decrease of water content, following lower temperatures acting upon protoplasm. Few adjustments are so simple, and, of course, more complicated ones became possible as atomic group after atomic group was added to the constituency of living matter.

---

[1] *Nature*, XXXI, 13, 1904.

Along with these acquisitions the feature of the rhythmic action which has become so characteristic and important for the living growth is to be considered, and this with contractility is dependent upon surface tension, viscosity, etc.

So far the properties suggested are those common to all living forms, but there must have ensued many differentiations of living matter, of which we have two survivals in plants and in animals. It seems probable that the first specialization resulted from the formation of substances in some of the living masses which converted radiations of certain wave-lengths into heat and other forms of energy active in promoting the reduction processes. A fortuitous movement toward such specialization may indeed have been the factor that made for survival in an environment of decreasingly available supply of chemical energy. The highest development of this power of absorption of light rays is to be assigned to chlorophyll, but preceding the formation of this very intricate and unstable substance there may have occurred a series of other compounds acting as heat-absorbent screens, of which the reddish and bluish pigments of the lower algae are surviving examples. Many disintegration products constituting the reds and blues of plant tissues sustain physical relations of a similar character to sunlight.

It is not possible to formulate any rational conception of living matter without including its environmental relations. These become of the utmost importance at the moment of formation of self-generating matter, and it may be assumed with perfect safety that of all the possible synthetic processes only those which ensued in the presence of a medium which furnished substances suitable for building material could survive. Furthermore, when the accumulation of this material and its specialization is considered it is apparent that successful origination occurred only on solid or semi-solid substrata rather than in undifferentiated solutions in open waters. Still an abundance of this liquid would be of great importance to the colloidal masses which we may think of as the earliest living things, and, as will be shown presently, water has continued to be the most important of all of the constituents of development especially with regard to the vegetal organism. The first method of multiplication of individuals or colloidal masses undoubtedly consisted of simple fragmentation resulting from the accumulation of a mass too great to be held together by surface tension, and the separation of these masses must have been accomplished, or made possible by flotation which continues to be one of the most efficient agencies in the dissemination of plants, a fact specially emphasized by the results of our studies upon the revegetation of the Salton Basin.

An early specialization of structure probably rested upon the reduction of portions of the self-renewing colloidal masses from the suspended condition of a sol to the condition of a gel, and doubtless the limiting membranes of protoplasmic masses depend upon this process. Likewise some form of centrum resulted from congelation processes by activities of a nature elementary to the relations of the nucleus and cytoplasm in the modern cell.

Wherever portions of the colloidal mass came into contact with solid substances gelation or aggregation ensued, and the masses of material thus differentiated would give form and stability in place, representing the earliest form of anchorage organ. In this as well as in other features of the plant, evolutionary development was slow so long as the monotonous conditions of an aquatic habitat were to be met. Very simple processes or extrusions from a cell or coenocyte of this general nature are still to be encountered among certain algae.

As soon, however, as it was left stranded by the disappearance of the shallow waters in which it may have lived, or was lifted above the water level by any means, the diversified conditions encountered by the organism, including desiccation, exercised a differentiating effect on the root-organ scarcely less marked than those which may be ascribed to the same agency in the shoot. The necessity for anchorage was no less, but now the nutritive substances no longer bathed the entire body but were present only in hygroscopic solutions on the soil particles with a vertical distribution not uniform, and with much horizontal irregularity. Survival depended upon the formation of specialized tracts for absorption, and conduits for the transport of solutions from the organ of fixation to other parts of the living mass. It is to be noted, however, that the modern root arose anew from the vegetative axis, and is therefore not directly derived from the primitive anchorage organs described.

The present occasion does not warrant a discussion of the evolutionary development of the vegetal organism from the colloidal mass to the gametophyte, now represented by the prothallium of ferns and their allies. Neither is it necessary to recall details of plant anatomy further than to point out that the earlier forms of plants, co-ordinately with the monotonous conditions offered by their acquatic habitats, showed no differentiation of tissues comparable with that of the axis of the modern seed-plant, and that their flattened bodies were for the most part closely appressed or adherent to the substrata. The development of the sexual type of reproduction in such forms had been followed by a habit of formation of the sexual organs separately, perhaps some distance apart on the upper or lower surfaces of the body. In the functionation of such organs the two kinds of protoplasts representing the sexual elements would be set free at the surface of the body and accomplish union while swimming freely, or in higher stages of development, the one representing the egg-cell would remain in place, while the fertilizing protoplast, or spermatozoon would find its way to it. In either case free water was absolutely necessary for reproduction. The body of the plant might be partially or completely immersed, or it might have only a thin film coating the surface, through which the sexual elements must move, but in either case the plant could not survive away from the margins of streams, seas, and lakes, or up out of the moist lowlands, or beyond the borders of rainy regions.

The thallose forms carrying on sexual reproduction do not appear to have been capable of the morphological development which might have gained them independence from the water, and this freedom was gained only after a secondary, asexual generation came into existence.

In the general movement which finally resulted in a land flora, the fertilized egg held in the body of the thallus would germinate in place, developing into a vegetative structure (the sporophyte) unlike the thallus which bore the egg. Then cells were cut off, or separated from the body of this alternate generation, known as the sporophyte, which had the power of developing into thalli like the original. Now the germination and growth of these asexually produced spores could proceed in the absence of free water, and in ordinary soil in which all of the water present was represented by the hygroscopic layer coating the minute particles of which it is composed.

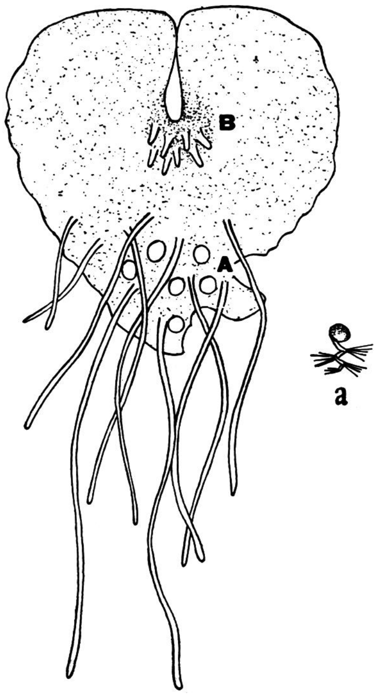

FIG. 2.—The gametophyte, or sexual generation of a fern. Reproduction is accomplished by the movement of a sperm (*a*) from the antheridium *A* to the archegonium *B* where it fuses with the egg, accomplishing fertilization. The sperm swims through a thin film of water which may be present. The absence of the film by aridity is unfavorable to the reproduction and continuation of this type of vegetation. The germination of the egg produces the sporophyte or fern plant ordinarily known (see Fig. 3).

Even with this development, however, plants could not get very far from the water, since this element in a free state was still necessary for the activities of the gametophyte, or sexual generation. The sporophyte, however, continued to increase in size and to wax in importance in the life-cycle of the species, until finally its body was much larger than that of the gametophyte. This feature is well illustrated by the tree ferns in which the sporophyte is a massive plant while the prothallium, or sexual generation, is a small thallose structure only a few millimeters across.

Eventually, however, the spores formed by the sporophyte, capable of living on dry land, were germinated in place, giving rise to sexual individuals, which were also held and nursed in the tissues of the sporophyte. Then in completion of the movement, accessory structures, including the pollen-tube, were formed, by which the sexual reproductive elements might be brought together independently of external conditions. By these steps the seed-plant originated and vegetation became truly and wholly able to occupy the land—a most momentous change, and one of great importance in connection with the general subject under consideration.

Temperatures alone have been unduly drawn upon in the interpretation of distributional features of ancient and existing floras, a fact made more plainly apparent by recent observations at the Desert Laboratory, in which it has been found that several species range over a vertical mile. Such species endure cold of −35° C. and have a growing season of less than a hundred days in the more boreal or alpine portion of their ranges, while in the southern or lower localities inhabited by them, temperatures of 48° C. may be encountered; the growing season extending over 300 days; the thermometer going below the freezing-point not more than 12 hours during the entire year.

It is with no surprise, therefore, that it is learned that there is no single feature in the structure and functionation of plants that with perfect assurance may be connected with the influence of temperature alone, although alpine and polar floras bear a distinct aspect by reason of a combination of conditions of moisture, insolation, duration of the seasons, and course of the humidity.

While temperature is not in itself a direct factor in shaping the general trend of evolutionary development in plants, yet it is indirectly concerned by the influence exerted upon precipitation, and the relation of the amount of the rainfall to the possible evaporation. The great changes in the climatic pattern of the surface of the earth, both in this and preceding periods, produced by whatever cause, may be taken to have affected vegetation chiefly through the humidity and desiccation effects, which not only determined the range and habitats of the species, but also played a predominant part in shaping the general development of the vegetal organism.

It will be profitable therefore to analyze the changes accompanying a modification of a climate toward or away from the desiccation of a region and the response of the flora to such altered conditions of environment. To do this most effectively let us suppose that the rainfall in New York, Pennsylvania, Labrador, Iowa, or Florida were reduced to one-fourth of the present amount by a gradual decrease through a long term of years. In the lower levels of the region affected, the total production of organic matter would be greatly lessened and consequently the amount of humus would decrease; wind erosion would remove much of this from its place of formation and by this means alone the distribution of many species would be totally altered. The soil moisture would ultimately be so depleted that the surface layers would show as great a proportion as the underlying layers, carrying an excess during seasons of precipitation, a fact that would have the profoundest influence upon the native vegetation, determining not only the habit of the root-systems, the form of the shoot, but also becoming a factor in distribution, and giving a new form to the competitive struggle among the organisms in a locality. The change in precipitation would result in the formation of long outwash, detrital slopes, or bajadas, giving new habitat conditions, and a further differentiation would consist in the surface deposition of soil salts, giving alkaline and saline areas upon which halophytic, or saline plants flourish. The lessened relative humidity would result in modification of foliar surfaces, make necessary for survival special structures in seeds and spores, and would be followed by a more intense insolation by reason of the non-absorption of some portions of the spectrum, and lastly the course of the temperature of the soil would change with the depletion of the humus and the altered water relations.

If desiccation ensued as a result of simple horizontal reduction of the precipitation, in a region with an unbroken surface lying at nearly the same level, the effect would be sweeping, monotonous, and with an almost total absence of selective effect that would mean extermination, or change in a flora *en bloc.* The majority of interpretations of the paleontological record assume such results. It is to be seen, however, that desiccation in a region with diversified topography and great differences in level would result in great differentiation, and if to this reduction is added the restriction of the rainfall to one or two brief seasons or to limited periods a maximum of effect may be expected.

The development of desert conditions in the manner described over a region of any extent would entail the least disturbance on mountain summits, where, by reason of the lowered temperature and the facilities for condensation, the evaporating power of the air would remain lowest. The original, or pre-desert forms would be able to maintain themselves on such elevated slopes with but little adjustment. Similar survivals might ensue along the lower drainage lines, where the underflow in streamways and washes might support a moisture-loving vegetation as it does in southwestern Africa and southwestern America. So much for survival by localization. A second manifestation would be shown by restriction of seasonal activities. The rate of evaporation on the lower levels might be lessened by lower temperatures during the winter season and at this time rapidly acting annual plants might carry through their cycle of activity, remaining dormant in the form of heavily coated seeds during the warmer, dryer period of the year. Perennials with deciduous leaves might display a coincident activity. This survival of moisture-loving plants in a region of pronounced desert character is most marked, however, in places where the precipitation occurs within definite moist or rainy seasons, such as the great Sonoran desert in which two maxima of precipitation occur, separated by periods of extreme drought. Both the winter and the summer rainy seasons are characterized by the luxuriant growth of broad-leaved annuals, which might not be distinguished from those of any moist region. Some species are active during the summer season, and others during the winter, while a smaller number perfect seeds during both seasons. A number of perennials parallel this activity of the annuals with the result that in the most arid parts of Arizona, according to the unpublished researches of V. M. Spalding, half of the native species are in no sense desert plants, requiring as much moisture for their development as do those of Maryland, Michigan, or Florida. The desiccation of a region is seen therefore not to result directly in the extermination of moisture-loving types, but rather to the reduction of their relative or numerical importance and a limitation of their activities to limited periods, or moist seasons.

Two types of vegetation may be definitely connected with arid conditions, representing as they do the morphogenic action of water which has been a predominant one in the development of the seed-plants. In one form the chief operation has been one of reduction and protection of surfaces. Leaves have been reduced to linear vestiges representing various parts of the foliar organ, branches to spines or short rudiments as in certain Fouquieriaceae,

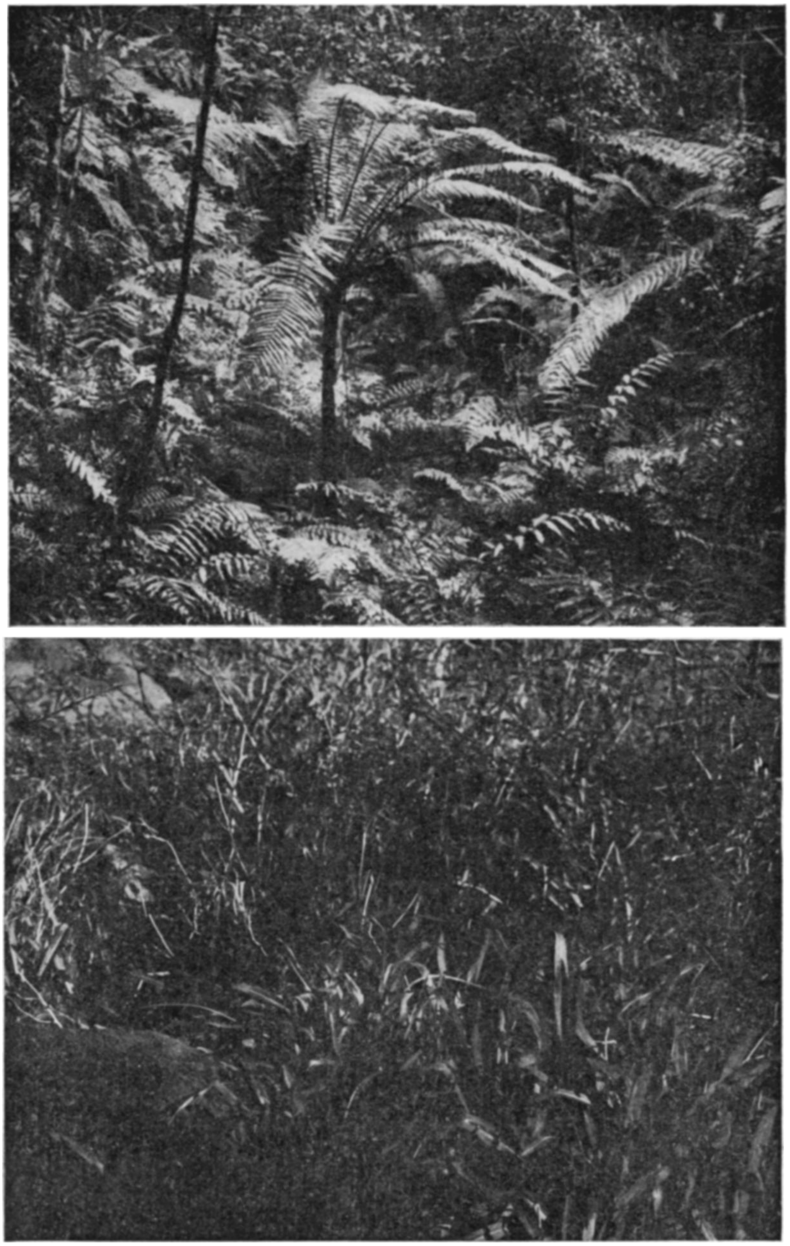

FIG. 3.—(Above) Tree-fern in a moist tropical forest in Jamaica, in which such plants survive. (Below) Dense carpet of borages and other annuals which grow from seed during the rainy season in the Tucson desert. These plants are similar in habit and structure to those of a moist region.

stomata show special constructions, and all parts of the shoot heavily coated and hardened; root-systems have been extended horizontally and the individuals thus isolated, being more or less accommodated to soils containing a large proportion of salts. The spinose, stubby, and switchlike perennials which result from such action are characteristic of low, inclosed desert basins, like the Salton, and those of southern Africa, and central Asia, where the scanty rainfall does not occur within such regular limits as to make distinct moist seasons.

The second form of desert vegetation is one in which the absorptive function has become highly developed and the capacity gained for conserving the surplus water taken up during the moister seasons. The Cactaceae are the most prominent representatives of this type in North America, and some of this group, as well as other species representing a wide range of families, have the capacity for sufficient water to meet the needs of the individual for a decade, while forms are known which might carry out their cycles of reproduction for a quarter of a century by the use of the surplus accumulated within their bodies. Such succulents display not only the reduction of the shoot and of the foliar surfaces together with induration of the epidermis, but have also this capacity for accumulating water and are hence desert plants par excellence, representing the apex of specialization to desiccation.

As a total result of the slow desiccation of any region, therefore, a very important proportion of the flora would consist of moisture-requiring species, or mesophytes, and the remainder would be included in two classes, the spinose forms with reduced shoots and roots, and the succulents with atrophied shoots, but with the additional development of storage structures in some organ of the shoot or root. The total number of species within an arid region is not less than that of the most densely closed tropical area, but the number of individuals is less, the interrelations of the individuals and species are not identical, and the competitive struggle for existence is of a nature widely different from that of a tropical forest. Increase in aridity tends to localization in distribution, and increase in humidity to diffuseness.

Evidence of the existence of xerophytes in previous periods of desiccation is extremely scanty. Calamites and lycopods with a slender central cylinder and a thick inclosing cylinder of thin-walled tissue have been alluded to in this connection, but these great

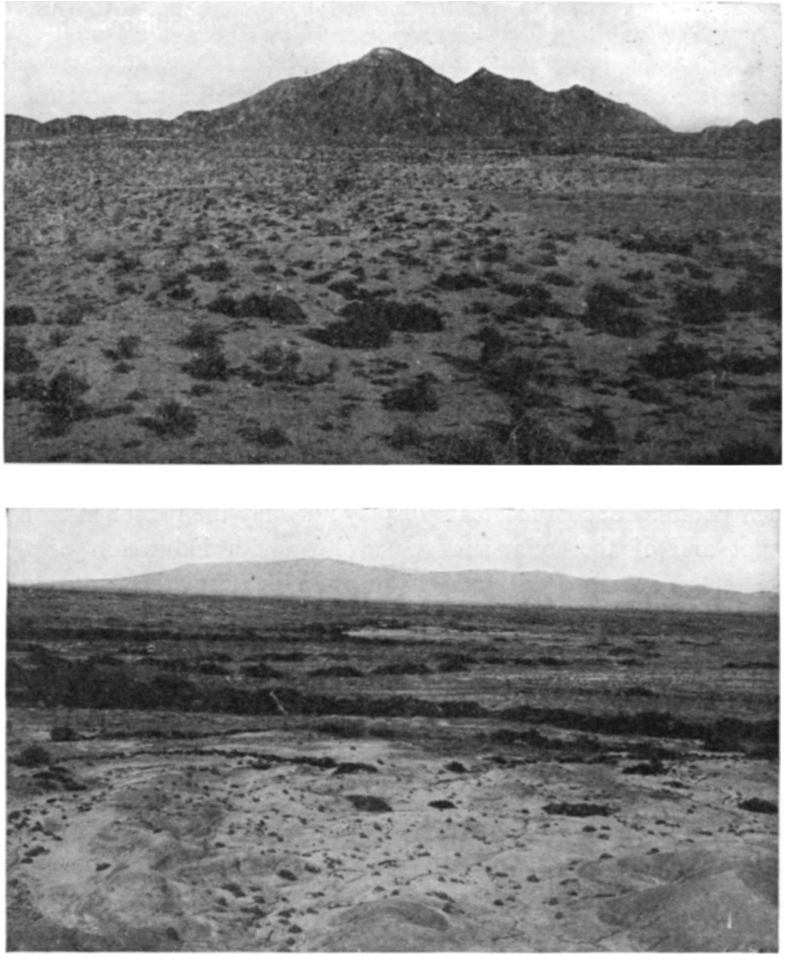

FIG. 4.—Aspect of the vegetation in regions with no well-marked rainy seasons of regular recurrence. (Above) The bolson of Las Vegas, Nevada. (Below) Bajadas of minor range of mountains near the shore of the Gulf of California, San Felipe Bay. The plants comprise spinose forms with very reduced shoots and leaves, which have not developed storage capacity.

sporophytes probably stood in swamps, or at least were hygrophytic in habit, and by the requirements of their separated gametophytic reproduction could not exist on land areas independently. It is also to be noted that many forms peculiar to swampy areas at the present time display reduced shoots and leaves of a specialized structure due to the action of certain constituents in the substratum, that they are known as "swamp xerophytes" and if brought to light as fossils might give the impression of having lived in an arid climate.

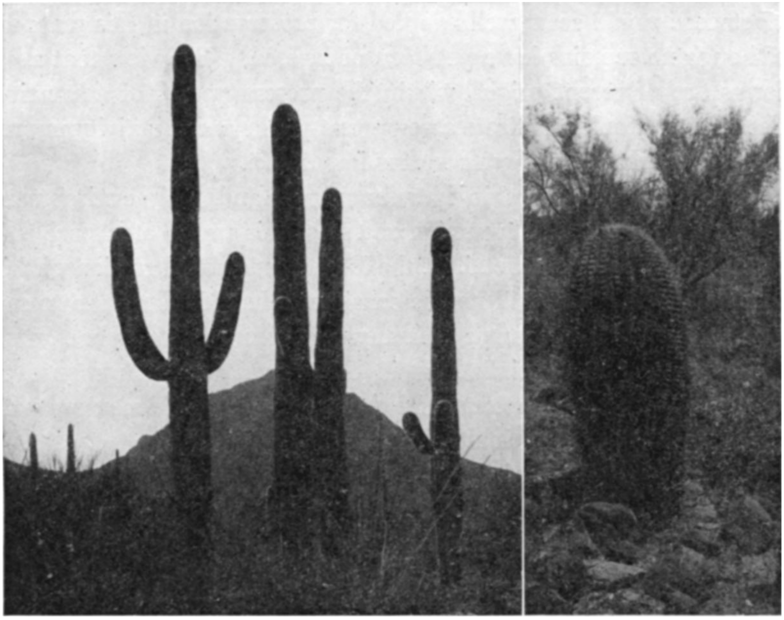

FIG. 5.—Types of plants from the Tucson desert, where two distinct yearly periods of maximum precipitation occur. In addition to the morphological reduction of the shoots and leaves, the capacity for the accumulation and retention of water has reached an enormous development. A group of sahuaros (*Carnegiea gigantea*) on the left; a single bisnaga (*Echinocactus Wislizenii*) on the right. The last-named plant has a supply sufficient for a dozen years' activity in its tissues.

The leaves of conifers very probably represent a specialization adapted to existence in a dry atmosphere, yet it is notable that the greater majority of surviving species live in soils in which the occurrence of moisture is not that of the desert.

The swollen stems of the Bennettitales offer the strongest suggestion of desert forms, and their structure and reproduction would make possible their maintenance as independent inhabitants of the dry land.

It is true, of course, that desert conditions are not favorable for fossilization, yet many opportunities for such action undoubtedly occur in the carrying and burying action of the torrential floods of desert streamways, while wind-blown deposits might preserve the more indurated forms. Many of these and the skeletons of the Cactaceae would seem well adapted for preservation in this manner, although no remains have yet been uncovered. The view that such forms are of recent origin, within the present period of advancing desiccation, would predicate a very great phylogenetic activity unprecedented perhaps, but by no means impossible.

The actual relationship between plants and their environment is by no means a settled question and since this and related problems are to be discussed in detail at the Darwin memorial session of this meeting, this subject will not be considered here farther than to say that it is unsafe to asssume that any organism has undergone adaptation and fitting specialization in direct somatogenic response to any set of environic factors, and that admissible evidence on such matters is extremely difficult to obtain.[1]

The operations of factors lessening the supply of water to any region would of course result in greater aridity in some places than in others and the movements of xerophytic forms established in these to other contiguous areas dried out later would be a matter in which the direction of the winds, streamways, movements of animals, and position of mountain barriers would play a determining part.

The recession of large expanses of water included in a desiccating region, such as has occurred in the great basins in Utah and Nevada, and in the bolsons to the southward and eastward in New Mexico, Chihuahua, and Arizona would present special conditions. The rate at which the waters of such inland seas might recede, however, would be such that the advance of vegetation to cover the immersed areas would be quite as rapid as that necessary to follow a receding ice-sheet or a change of climate due to any cause. Thus our observations on the Salton Lake show that beaches a mile in width are bared within a year, while the agencies most effective in their revegetation are combined wind action and flotation.

---

[1] *Fifty Years of Darwinism.* New York: H. Holt & Co., 1909.

Many areas, such as the central basin of Asia, the American desert, the Eyre Basin in Australia, and southern Africa, offer clear examples of the effect of desiccation upon the vegetation of a region, but when we proceed to the consideration of the probable happenings when an arid region receives an increasing precipitation, our speculations must be based wholly on experimental evidence of the physiological behavior of plants under known conditions.

Here, as in the decrease of the supply of water, no mass movement or extermination of a flora is to be taken for granted. Many highly specialized succulents extremely local in their distribution would undoubtedly quickly perish with the progression of a climate bringing an excess of moisture; alterations in temperature would not exercise such violent action upon plants of wider range, however. That both together might not totally exterminate a type of succulent is shown by the existence of cacti in tropical rain-forests and on the high northern plains of Nevada, Idaho, and Montana. If plants of wider latitudinal distribution are taken into consideration it may be seen that with an advance of polar climate to the southward the extermination of a species in the northern part of its range would be coincident with additions to the eligible area on the southward. If the land area were limited or if mountain barriers intervened, such dissemination would of course be impracticable and the forms involved would soon perish. These features must be taken into account in an interpretation of the flora of the inclosed basin of central Asia, which, so far as the meager information available shows, is extremely poor in the higher succulent desert types, a characteristic also of the Death Valley and of the Salton Basin in North America.

The unfavorable influence of increasing moisture upon the xerophytic forms of a region would also include effects of an indirect character. Soil temperature and moisture relations would undergo great alterations, humus would increase, and other changes would ensue, entailing conditions which their specialized structures would be unfitted to meet. Furthermore, succulent and spinose plants being advanced types, their retrogressive evolution to conform to moist conditions would be a process resulting in enormous loss of species. Some spinose types would seem to offer the best morphological features for such a change.

Perhaps the most inportant of all of the altered conditions brought about by increasing moisture, however, would be the total transformation of the competitive struggle for existence. Animals would no longer play the predominating rôle as in arid areas. The number of individuals representing the constituent species of a flora would be multiplied a hundred fold, perhaps a thousand fold, and once more the amount of food material offered to animals would decrease their total importance as a factor in selection, while the intensest crowding between roots and between shoots would once more be resumed and horizontal differentiation of associations such as that in forests would ensue.

The element of a desert flora which would respond most readily to ameliorated aridity would, of course, be the hygrophytic annuals and perennials, which had survived the period of desiccation in their refuge of the rainy seasons, and in the moist areas along streamways and on elevated peaks. These would quickly occupy the greater part of the surfaces available for plants to the great intensification of the inter-vegetal struggle for existence. As these hygrophytes survived in the moist situations and the moist seasons of an arid period, so the surviving xerophytes in a moist period would find refuge in restricted habitats on talus slopes, rocks, and sand in which the soil-moisture relations would be best suited to their specialized structure and might display their seasonal activity during a period of the year in which the precipitation was least.

Briefly restating the principal ideas touched upon, it may be said that Chamberlin's prothesis of the planetesimal aggregation of the outer portions of the earth and the attendant conditions, together with current theories as to the catalytic nature of the essential activities of protoplasm, makes possible rational speculations upon the origination of self-organizing matter.

The passing of nitrates, phosphides, carbides, and sulphides into more stable combinations might readily result in the formation of thermo-catalysts, one type of which survived in the later forms of living matter. Similar combinations do not appear to be taking place at the present time, and their accomplishment experimentally is attended with difficulties not yet surmounted.

The part of the evolution of living matter which may be brought under observation in living forms or preserved material represents very advanced stages and the cell is separated by a wide range of development from the colloidal masses in which self-generating matter first took form. The construction of substances which might use or transform energy other than that of chemical structure represents the first differentiation between the animal and vegetable organisms.

Plants were necessarily confined to aquatic or hygrophytic habitats as long as their history included the free gametophyte, and a land flora became possible only with the development of the sporophyte culminating in the derivation of the seed-plants. In this and in subsequent history the water-relation has played the predominating morphogenic rôle.

The desiccation of a region occupied by a land flora would entail a complex series of changes in climatic and other environmental factors which may be followed by extermination or differentiation of the flora. This differentiation, which would ensue most readily in regions of diversified topography, with an absence of barriers preventing distributional adjustments, would include localizations of habitats, seasonal restriction of activity, and transformation of the competitive struggle for existence from one chiefly among plants to one between plants and animals.

The surviving flora would include an important proportion of mesophytes or hygrophytes, while the arid conditions might be followed by the development of two types of xerophytes, succulents, and spinose forms.

The amelioration of desert conditions would mean a reversal or shifting of various environic factors, the whole favoring the increase in the number of individuals representing the mesophytes, the widening of their habitats, and the institution of the fiercer competition among plants. Such changes would force a retrogressive development on the xerophytes, exterminating many, restricting the range of all, and would result in the survival of a few under conditions wholly foreign and antagonistic to those in which their characteristic qualities originated.

In all attempts to correlate ancient floras and interpret the climate of formations, especially with regard to aridity, the following features are to be taken into account:

Vegetation of diverse lower types might cover moist lowlands, make a profuse growth along streams, or clog extensive stretches of shallow waters in seas and lakes, but only seed-plants could occupy dry land. It is to be borne in mind that the forms representing this advanced type must have constituted a small proportion of the vegetation for a long period after their origination. Their present predominance must be a very modern feature. Furthermore, the dissemination of new forms proceeds somewhat slowly and it is by no means to be taken for granted that the existence of seed-plants, as denoted by fossil remains, is to be taken as an indication that such plants occupied or covered great continental areas. Soil conditions would be a very important factor in such distribution.

The distinction between the vegetation of a region in alternating moist and arid epochs may not easily be made, since as has been pointed out the fossilization of the flora of the Arizona Sonora desert would probably result in material richer in moisture-requiring plants than in xerophytes. The morphological features of the forms preserved would offer the most valuable evidence, and the presence of a single xerophyte among a hundred forms requiring moisture would be of great significance.

The final stages in the differentiation of the land flora, by which spinose and succulent xerophytes have come into existence, seems to have been reached within very recent times. No fossil remains of desert plants have yet been recovered. Some of the forms which have the aspect of xerophytes must have grown in moist regions by reason of their method of reproduction. Some of the cycads and the conifers may be regarded as being most suitable of the older types for existence under arid conditions. The fitness of these plants is due almost wholly to features of the shoot, and the known features of their root-systems offer nothing suggestive of adaptability for the characteristic soil conditions of the desert.